

SIMULATING THE RAINFALL-RUNOFF PROCESS ON THE BASIN OF BÜKKÖS CREEK

by

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ABSTRACT

It has become basically relevant to get an appropriate introspection in catchment processes in order to predict floods which may occur easily under the extreme weather conditions of nowadays. Numerous empirical formulas exist in Hungary, which can be applied within certain limits (season, size of the watershed), furthermore using them in specific watersheds eventuate dissimilar results. In our study we execute hydrological analysis of a small watershed namely, the basin of Bükkös Creek, found in the Hungarian Visegrád Mountain. The discharge values received from the authorities were checked by expeditional measurements several times at the outlet in 2011. These data were the foundations of the further calculated unit hydrograph (with traditional hydrologic methods) and rating curve. Finally we built a HEC-HMS model to simulate the hydrologic response of the watershed for different rain events. By calibrating and validating the model for two periods (winter and spring) with different runoff ratios, we were able to provide an approximation not only for the peak discharge but also for the whole runoff volume.

Keywords: hydrological modelling, rainfall-runoff simulation, unit hydrograph

1 INTRODUCTION

The extreme circumstances of weather conditions could be one of the effects of the global climatic change. For instance, short rainfalls with increasing intensity. It is a well-known fact that severe thunderstorms often result significant floods on small catchments.

Bükkös Creek has been brought several times to national attention in the latest years. Due to heavy rains, remarkable floods ran along the creek; local people were moved from their homes because the stream left its bed.

Our work compiled of the following steps: wandering all over the territory, we got acquainted with the hydrologic nature of the watershed; furthermore we got an approximate introspection in the range of the runoff volume with the hydrological measurements at different points of the creek.

Water level and runoff data, as well as contemporaneous precipitation data received from the authorities were the inputs of our hydrological analyzes. If a real rain event in frost-free periods is given on the catchment, with the hand of the computed rating curve and unit hydrograph, we can describe the behavior of the watershed. This could definitely relieve the procedure of predicting floods.

We built a HEC-HMS model to simulate the hydrologic response of the watershed to different rain events. By calibrating and validating the model for two periods (winter and spring) with different runoff ratios, we were able to provide an approximation not only for the peak discharge but also for the whole runoff volume. The amount of input data and free parameters demanded by the software is truly high. We present our experiences with the model, the opportunities and barriers lying concealed beneath this approach. Finally we give samples of some model applications.

2 DESCRIPTION OF THE STUDY AREA

The investigated area can be found to south from the Curve of Danube in Hungary. The creek feeds into the Danube in Szentendre, it is the most remarkable permanent watercourse of the city (*Figure 1*).

The total area of the catchment is 39.2 km². The creek is 16 km long, having a constructed bed in the urban area, which is well protected by levees from floods.

It originates from the southern slopes of Dobogókő, nearly 600 m above the mean sea level, from where through a way varied with numerous mite waterfalls and making a level difference of 500 m, it arrives to the interior part of Szentendre.

The main aquifers of the streams feeding the creek are andesite and andesite-tufa with a strongly watertight nature. The runoff volume is quite variable during the year, relatively exiguous, however we managed to measure larger amount of discharge in spring, when snow melted.

The discharge of the brook fluctuates between great extremenesses. The creek along its way could not form ponds, because the evolving hollows are quickly filled up with alluvium (Dövényi, 2010).

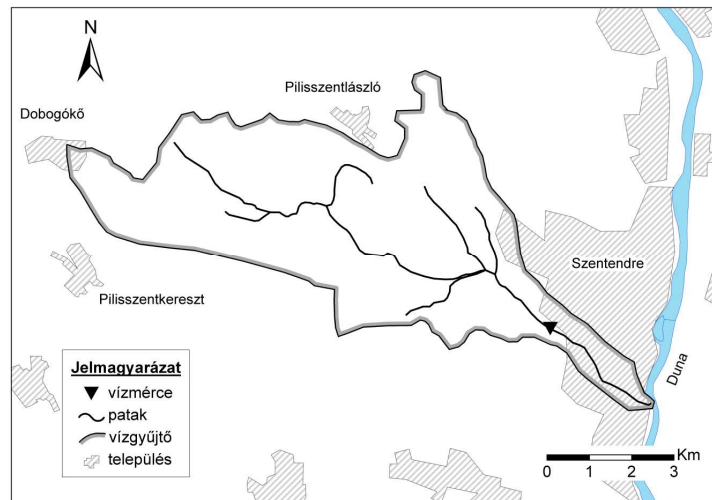


Figure 1 – Watershed of Bükkös Creek

3 HYDROLOGICAL ANALYSIS WITH TRADITIONAL METHODS

3.1 Data and field measurements

Hydrologic calculations and model simulations required discharge data which are frequent and accurate enough.

Central Danube Valley Environmental and Water Management Directorate (KDV-KÖVIZIG) installed a compound trapezoidal concrete flume with a floating instrument registering data per 15 minutes. This gauge is located 4.2 river kilometers upstream from the confluence with the Danube. The area of the catchment to the gauge is 33.4 km².

The authority placed at our disposal the daily water surface level data recorded by the gauge from 2005 to 2009 and in 2011, furthermore the calculated (from the water surface level data with the help of an appropriate rating curve) and several times manually measured discharge data, as well as the data of more remarkable floods since 2005. The latter data have temporal resolution of 15 minutes, and were used to simulate the precipitation-runoff processes of the watershed with HEC-HMS.

The discharge values received from the authorities were checked by expedition measurements several times at the outlet in 2011 (dilution gauging and velocity-area method using current meter).

3.2 Precipitation data

Building up a proper hydrological model, more detailed precipitation data are needed than for example daily data. The nearest precipitation gauge (about 25 km far), which fulfils this criterion, is found in Újpest, Budapest, operated by the Hungarian Meteorological Service (OMSZ). We received hourly measured precipitation data from the authority.

3.3 Constructing a rating curve

The received flood data fell mainly in the period from 2010 to 2011. Model analyses demand discharge data, generated by a proper rating curve.

The equations of rating curves were calculated by fitting a cubic polynomial on the discharge (Q) and water surface elevation (H) point clouds with least squares method.

Out of the five years, with an appropriate approximation, each of them fits on the rating curve of 2009. For this reason, we have chosen this year's curve for further calculations. *Figure 2* illustrates the rating curve of the year 2009.

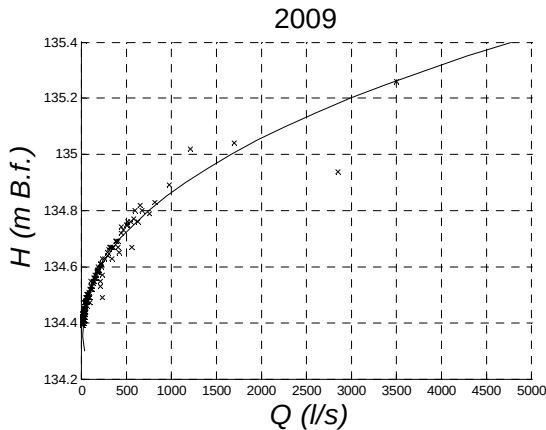


Figure 2 – Rating curve of the year 2009

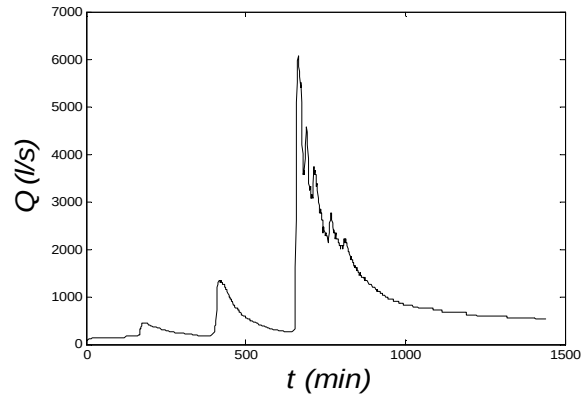


Figure 3 – Calculated discharge data of a flood in 2006

We generated discharge data of 15 minutes for every flood event on the above described way, set out from the water surface elevation data in every 15 minutes at the same time. *Figure 3* shows the calculated discharge data of a flood taking place in 2006.

3.4 Creation of unit hydrograph

The baseline data of the edited unit hydrograph were the calculated runoff data of a flood in May 2010 with 15 minutes time step and hourly precipitation data received from OMSZ (see *Figure 4*).

We selected this flood event out of the 14 others, because on one hand the precipitation was significant, on the other hand the peak flow occurred in appropriate time following the start of the rainfall event.

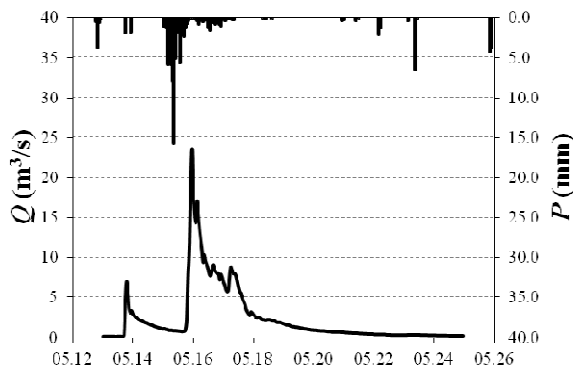


Figure 4 – Precipitation and calculated discharge in May 2010

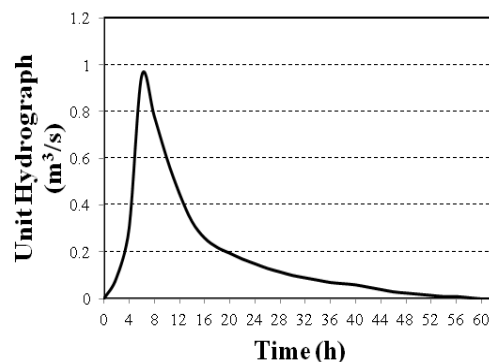


Figure 5 – Straightened unit hydrograph with 4 hours time resolution

The magnitude of the calculated runoff volume was controlled by Chézy-equation, because this discharge is not included in the rating curve, an extrapolation has to be performed. The slope of the curve is little in this range, yielding a significant uncertainty in extrapolation. The result of the Chézy-equation was $24.8 \text{ m}^3/\text{s}$, which truly matches with the calculated one.

We decided to work with a unit hydrograph with a resolution of 4 hours in time, easing the calculation, because the flood event in May 2010 lasted 12 days.

Both of the rainfall, which triggered flood wave, and peak flow appeared between 15 and 17 May. A little amount of rain falling from 14 to 17 hour on the 15th May 2010 was considered as a so called preparing precipitation, so only the precipitation data from 17 to 24 hour on the same day were taken to account as flash food resulting data. 24.3 mm precipitation fell during the first 4 hours and 21.2 mm during the following 4 ones. Totally it was 45.5 mm.

The oscillating runoff data were manually straightened in the course of separating discharge data of the flood. We had only few information about the under surface properties of the watershed, for this reason the moment of the beginning of flood was matched with the end of surface runoff. The area under this line represented baseflow and the area between this line and the curve of the flood formed the quantity of direct flow. Runoff data could be added up along the determination of direct flow due to the dense scale of time axis. Total runoff volume was then multiplied by $4 \cdot 3600 \text{ s}$, resulting in total runoff (the area under the curve was approached with summing up the areas of rectangles). The ordinates of unit hydrograph can be easily calculated with effective precipitation data using the classical method of ‘rolling up’. Every second ordinate had a negative value ending up an oscillating curve. *Figure 5* illustrates the straightened unit hydrograph.

4 SIMULATING PRECIPITATION-RUNOFF PROCESSES WITH HEC-HMS

HEC-HMS (Hydrologic Engineering Center’s Hydrologic Modeling System) is designed to simulate the precipitation-runoff processes of dendritic watershed systems, being developed by U.S. Army Corps of Engineers for nearly 30 years. It offers a broad range of hydrologic and hydraulic methods to describe watersheds properly. The main components of the program are: basin model and meteorological model, input data and control specifications.

The basin model represents the physical watershed developed by adding and connecting hydrologic elements. Three of them were used by us: watershed, reach and junction. *Figure 6* shows a simplified basin with the three used model components.

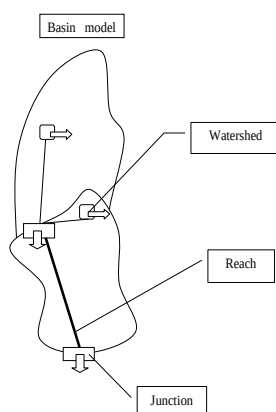


Figure 6 – Hydrologic model components of a simplified basin

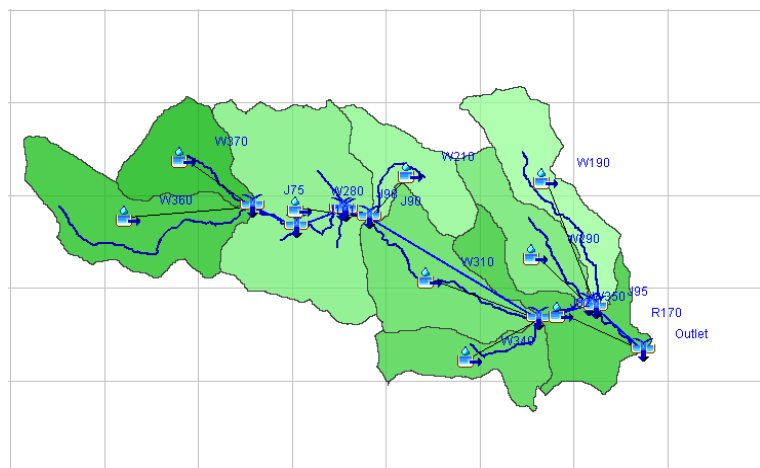


Figure 7 – Basin model of Bükkös watershed (made by Gábor Keve).

Subbasins are represented as points, the size of them have to be given. The junction element is used to combine stream flow from hydrologic elements located upstream of the junction element. The reach element conveys stream flow downstream in the basin model, whose length is demanded to be given by some of the

calculation methods. *Figure 7* shows the basin model of Bükkös Creek used by the model. It is easily recognizable that complexity of the used basin model made model calibration definitely difficult.

Meteorological model calculates the frozen or liquid precipitation and evapotranspiration. We dealt with only liquid precipitation.

We assumed a homogeneous spatial distribution of rain, because only one precipitation gauge's data were available.

4.1 Hydrologic elements of the model

HEC-HMS offers the users numerous calculation methods developed in the United States of America. Therefore applying these methods in Hungarian catchments and accepting the parameters suggested by user's guides requires a proper attention considering the different climate and topography of Hungary.

Calculation methods used by us are presented below (*Table 1*). Such as this table shows, we had to calibrate nine different parameters.

Table 1: Applied methods and their parameters

Methods	Parameters
Simple Canopy	Initial storage (%) Max storage (mm)
Initial and Constant Loss	Initial loss (mm) Constant rate (mm/hr)
SCS Unit Hydrograph	Impervious (%) Lag time (min) GW 1/2 Initial (m ³ /s)
Linear Reservoir Baseflow	GW 1 Coefficient (hr) GW 2 Coefficient (hr) GW 1/2 Reservoir (-)
Lag Routing	Lag Time (min)

4.2 Selecting time periods of examinations

14 periods of precipitation-runoff data pairs were available to set up, control and analyze the model. Furthermore eight of them are cognate. Sometimes there is even 10 hours time delay between occurring of the peak flow and the center of the rainfall event. This is the consequence of the large distance between the precipitation gauge and the watershed (Újpest is located nearly 25 km from Szentendre). As it was previously mentioned, this gauge was the nearest one, which was able to record automatically precipitation in every hour. Under these circumstances we had no opportunity to analyze long periods and all of the flood events.

At least two flood events, observed in the same season, were needed to calibrate and validate the model. Runoff characteristics are definitely changed in different growing seasons, in this way floods in summer or winter time cannot be treated uniformly. The runoff volume of peak floods and maximal precipitation intensity were depicted in the same graph. According to the dispersion of data, it is clearly recognizable that there is no tight relationship between them. Maximal runoff volume and precipitation, as two, not independent random variable with a stochastic relationship, have to have a stable correlation link. Satisfying this condition, the next time periods were used for model simulations in winter and early spring:

- January 2011,
- February 2009,

as well as:

- March 2011,
- April 2010.

4.3 Model calibration

Our primary purpose was to approximate the discharge time series of a flood in a significant cross section intending to obtain the greatest matching at peak flows. Naturally we tried to take account of the correct shape and timing of the food, with choosing the right parameters.

The precipitation was liquid according to the data received from Hungarian Meteorological Service thus snowmelt did not complicate the simulations.

At first only loss, transformation and lag routing were taken into account to reduce the number of free parameters. Therefore simulations ended up in too rapid runoff, the slope of the hydrographs became steep. For this reason, we found it necessary to introduce baseflow. The form of the hydrograph became more regular and wider. The only problem was that the program overestimated the real, measured discharge data. This indicated another loss on the catchment. A decrease in surface runoff could have numerous reasons, such as interception or surface depressions. This combined effect was modeled by introducing canopy, a specified amount of water remaining on the leaves of trees. Finally the number of free parameters was finally nine.

The same parameters were given to each watershed and reach elements during the calculation of baseflow and loss. The total lag time was divided between each watershed in proportion of each watershed' area during the calibration of SCS unit hydrograph and it was divided between reach elements in proportion of the length of each reach during the calibration of lag routing.

The model was calibrated in two different time period, a winter and a spring one. Parameters of spring period, when the infiltration capacity of soil is intensive resulting in a larger baseflow, significantly differed from the parameters of the winter period, when ground is frozen. In line with this, interception, infiltration and baseflow were enlarged in the spring period compared to the winter ones. Other parameters were not changed (transform methods, routing time and number of reservoirs). All in all the two calibrations have three common parameters.

Figure 8 illustrates the calibration of the winter period in January 2011, where runoff calculated by the model is with solid line; measured runoff is with dashed line; precipitation is represented with bar graph. The result of the calibration of the spring period in March 2011 can be seen on Figure 9.

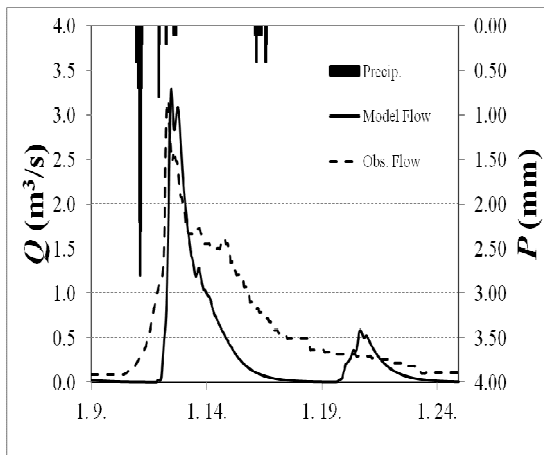


Figure 8 – Calibration in January 2011. (Runoff calculated by the model with solid line; measured runoff with dashed line; precipitation with bar graph)

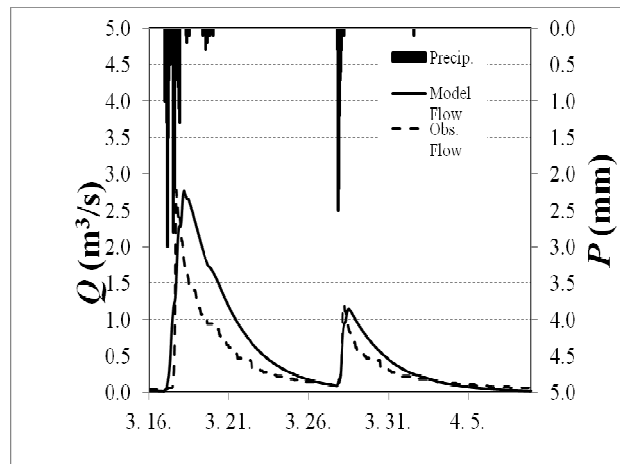


Figure 9 – Calibration in March 2011 (see notation at Figure 8)

4.4 Validation of the model

Validation was performed with independent floods. The values of parameters were not changed. Figure 10 shows the result of the validation in February 2009, where real peak discharge is somewhat underestimated (with about 1.5 m³/s), but this is not a significant error, having regard to the fact that the calculated discharge

fits the real one quite well at smaller discharge values as well. We also have to take the uncertainty of input data and parameters into consideration when the accuracy of the model is examined.

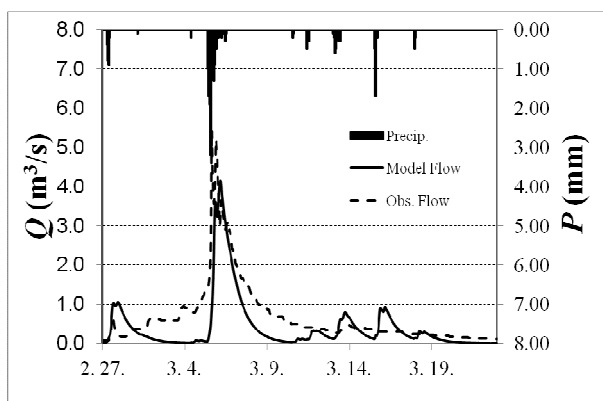


Figure 10 – Validation in February 2009 (see notation at Figure 8)

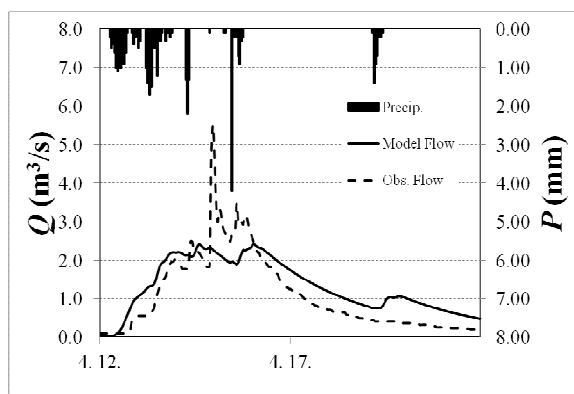


Figure 11 – Validation in April 2010 (see notation at Figure 8)

Figure 11 illustrates the validation in April 2010. The form of the calculated discharge fits truly well in the measured discharge data in time and also in order of magnitude. However the model underestimates runoff volume. The slope of the peak flow has definitely grown, referring to the fact that a short and rapid precipitation event occurred on the catchment, which did not reach the precipitation gauge.

4.5 Model application and analysis

Hydraulic and water resources engineering works and watershed management of smaller catchments are planned in the hypothetical circumstances of standard high-water conditions. Peak flows and quantity of runoff volume have to be well known. Precipitation causing significant floods with low probability of return can be estimated with analyzing precipitation data of previous years. Floods caused by such rainfall events in different time periods can be determined by a well validated model. We managed to perform this and compared with a hydrograph generated with the unit hydrograph.

The rain intensity was defined on the basis of intensity-duration-frequency analysis with the application of Montanari relation (Kontur et al 2003). It is an experience that severe storms result in flash floods on small watersheds, when total time of precipitation is equal to accumulation time. This means about 4 or 8 hours on our long-drawn watershed. We chose a 4 hours long lasting rainfall event with a constant intensity of 10 mm/h as a significant precipitation. There is another peak on the dashed graph of

Figure 12, which is derived from the shape of the watershed, the number of subbasins and on the fact that spatially uniform precipitation was assumed. Propriety of this is questionable. Peak flow and the magnitude of drainage are acceptable.

Calculations were also performed with spring model parameters.

Figure 12 illustrates this with dashed-dot line. Runoff time was longer due to changed ground conditions and vegetation coverage. Floods endured 2 days in winter, but from 5 to 6 days in spring. Peak flow is naturally reduced to one-fifth or sixth. Figure 12 shows discharge data calculated by the unit hydrograph with solid line. Runoff time is shorter than it was expected, but peak flow is relatively acceptable.

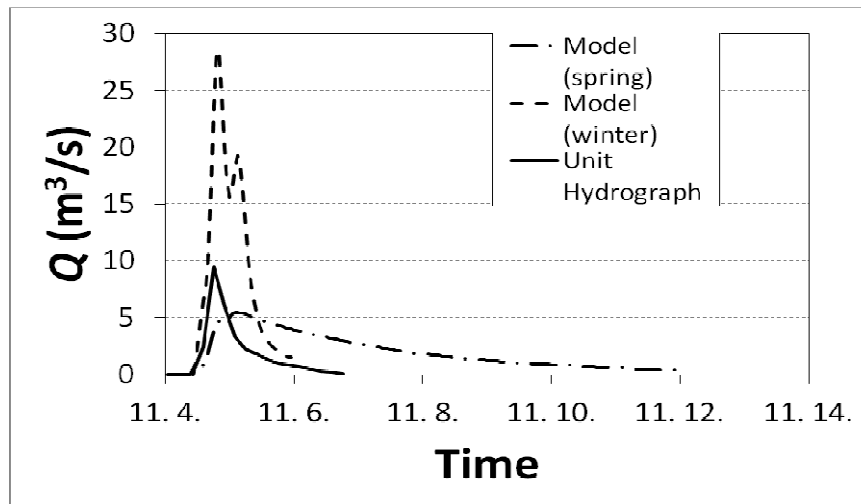


Figure 12 – Model analysis (runoff calculated by the model with dashed-dot lines in spring and dashed line in winter; runoff calculated by unit hydrograph with solid line).

5 CONCLUSIONS

In default of more acceptable data, we could validate the model (both of the spring and winter one) with only one flood event. However it would be required to perform control runs with more data. The reason of this is that the model needs a large number of input parameters which could be reduced by transforming the basin model and calculating with fewer subbasins. According to our expectations these reductions would not influence the accuracy of results but significantly facilitate calibration.

Spatial and temporal distribution of precipitation are variable, however Bükkös Creek is a small watershed, and this effects discharge at the outlet (for instance, the peak flood or the runoff ratio).

We managed to calibrate the model with two different hydrological events, which itself was an opportunity to perform model analyzes and explore different processes of the catchment. Vegetation coverage and soil characteristics radically change between winter and spring period in only a few months time, modifying runoff relationships. The most important conclusions of these changes:

- Losses increase (3 or 5 times bigger in spring than in winter).
- Infiltration capacity of the soil also increases. The ratio of direct runoff and baseflow changes. Infiltration to the ground is also 3 or 5 times larger in spring than in winter.
- Standard high water conditions in a watershed located in a hilly or mountainous terrain can be resulted by snow melt according to model analyzes and site visits despite the largest flood was measured in May.

The model needs a high amount of input parameters. A sensitivity analysis should be performed with these. It would be worth to try other calculation methods. We could define concrete algorithms on different watersheds with the help of involving other territories to model analyzes. We could choose the most correct calculation method which best suits the concrete catchment.

Quantity and quality of precipitation data influenced the precision of model tests the most. Out of 14 flood events, only 4 could be analyzed, because precipitation and flood data were not coherent: nor in time or in magnitude. Rain gauge was located too far from the catchment. Installation of precipitation gauges on the watershed would be necessary. Temporal resolution of fixing data depends on the area of the watershed. In our case (30-50 km²) an hour resolution can be proper.

6 REFERENCES

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